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ATMOSPHERIC ELECTRICAL SOUNDINGS AND THEIR RELATION TO PRECIPITATION

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ABSTRACT

Forty-five Aircraft soundings were flown over West Plains, Missouri, during the summer of 1963 to determine the" electrical nature of the atmosphere up to 10,000 feet msl. The results from the soundings obtained are described and compared with the occurrence or nonoccurrence of precipitation in the 5 hours following each sounding. Usually the potential gradient was found to increase in the first 1000 to 3000 feet above the surface and then decrease to the top of the sounding. Early afternoon soundings which were followed by precipitation showed an unusually high potential gradient above 7000 feet, but a similar situation occurred in the presence of vertical mixing to 10,000 feet in the absence of precipitation. It is conqluded that precipitation is not preceded by a unique set of atmospheric electrical conditions in the lower atmosphere.

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INTRODUCTION

Of the many theories which have been advanced to explain thunderstorm electrification, all but a few have been discarded as not fulfilling criteria set forth by our present knowledge of thunderstorm dynamics, electrification, and microphysics. Of the thunderstorm theories being considered at present by atmospheric electricians, none has been conclusively shown to be the only mechanism operative in all thunderstorms. At the same time, recent laboratory studies have been accumulating evidence indicating that cloud electrification enhances the precipitation processes. If precipitation formation is to a degree dependent upon cloud electrification, then the importance of understanding how the electrification originates is of increasing importance.

In 1954[2] , Dr. Bernard Vonnegut proposed that convective clouds become electrified by a self-enhancing process initiated by the normal fair-weather space charge. He suggested that fair-weather positive space charge is convected into the cloud which in turn attracts negative space charge to its periphery. The negative space charge is carried to the region of the cloud base by downdrafts at the cloud's surface. When the negative space charge near the cloud base becomes intense enough it causes pointed objects on the surface of the earth to go into point discharge, increasing the concentration of positive space charge convected into the cloud. The process enhances itself until the upper portion of the cloud attains a large positive charge and the lower portion of the cloud a negative charge.

This author hypothesized that if this mechanism is indeed existent in nature, and because it would be dependent upon the atmospheric space charge, it is reasonable to assume that the atmosphere might exhibit differences in its electrical properties between days which produce precipitation and days which do not.

To investigate the possibility of the electrical nature of the atmosphere being different on rain and no-rain days, a series of 45 aircraft soundings were made near West Plains, Missouri, during the summer of 1963. Measurements were made of the vertical potential gradient, positive and negative conductivity, temperature, and humidity as well as the altitude, pitch, and roll of the aircraft. Raingage rainfall data were taken by the University of Chicago within a 60-mile radius of their TPS-10 radar as part of Project White Top.

INSTRUMENTATION

The aircraft used for the soundings was a C-45, twin-engine Beechcraft, equipped by the researcher. Signals from the various sensors were recorded on a 24-channel Visicorder oscillograph. The instrumentation used for measuring the vertical potential gradient is similar to that reported by Vonnegut et al.[3] It consists of two radioactive probes mounted symmetrically above and beneath the wing. The probes are connected to an electrometer through a potential-to-current transducer. The transducer is such that the relative coupling of the individual probe inputs can be adjusted so that the potential of each probe due entirely to charge on the aircraft is the same. Since the transducer output is proportional to the potential difference between the probes, the effect of the aircraft charge is cancelled. The transducer output is then amplified by a one-tube electrometer and recorded on the Visicorder. After each flight, known voltages are applied to the inputs of the transducer for calibration. The overall augmentation factor of the aircraft for the potential gradient was determined" by making several low-level passes over a ground potential gradient measuring station located at a grass landing strip at the University of Illinois airport.

A similar device was also used to measure the horizontal potential gradient, but because of the sensitivity of the device to the roll of the aircraft and the resulting complexity of the data, the data were not used.

The positive and negative polar conductivities were measured alternately with an Applied Physics Corporation Gerdien tube and vibrating reed electrometer. The Gerdien tube and preamplifier are mounted in the nose of the aircraft. Air is ducted into the condenser through a 1-inch diameter tube protruding 17 inches from the nose of the aircraft into undisturbed air. Inside the aircraft's nose the tube expands to the 4-inch diameter of the Gerdien tube. The exhausted air is ducted out the side of the plane through a reverse scoop. The device alternately measures positive and negative conductivity, followed by a zero measurement made by the grounding tube.

A space charge filter similar to that used by Moore et al.[4] was aboard the aircraft to measure directly space charge concentrations, but, technical difficulties in the instrument prohibited the collection of data.

Temperature and humidity measurements' were' made with an AMQ-7 temperature and humidity sensor utilizing a carbon humidity element and thermistor.

Rainfall data used in this report were obtained from 16 U. S. Weather Bureau recording raingages plus 21 recording gages installed by the University of Chicago for Project Whitetop. Figure 1 shows the location of the gages.

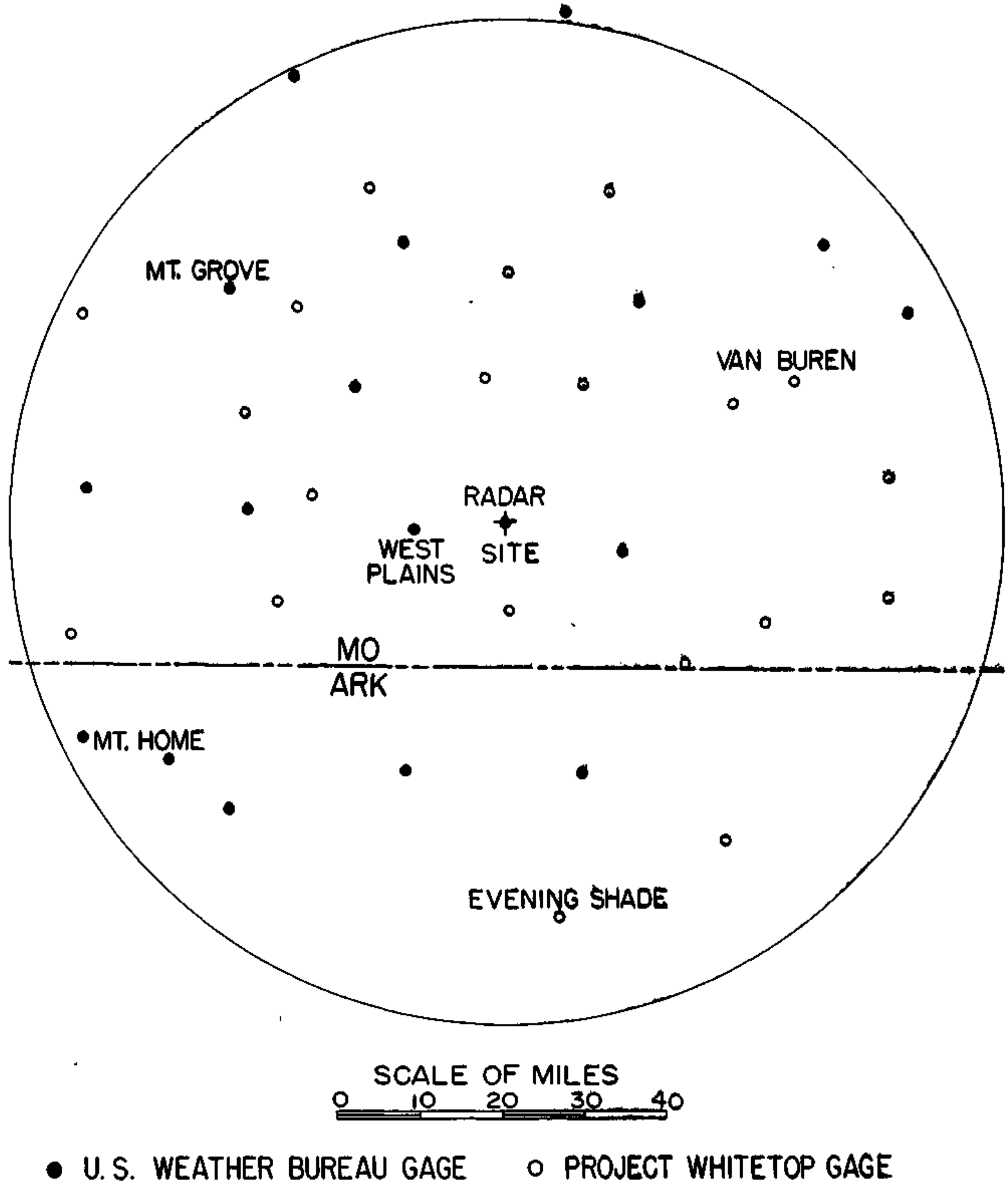

Fig. 1. University of Chicago and U. S. Weather Bueau raingages,

Summer 1963.

OPERATIONS

Aircraft operations were centered at the Project" Whitetop field station at the Municipal Airport in West Plains, Missouri; Forty-five flights were made during the two periods of July 13-26 and August 1-14. Aircraft soundings were made when possible twice a day at approximately 0830 CST and 1415 CST. Flight paths were usually in a southerly direction in a straight line unless a course change was necessary to avoid clouds. Ascent and descent rates of 500 feet per minute were used with measurements taken both ascending and descending.

Few electrical measurements taken in the first several hundred feet above ground were used for two reasons. The airport runway was constructed of bare clay and, except after rain-, was very dry and dusty. The large clouds of dust created during takeoff" produced a considerable temporary charge on the aircraft, and evidence indicated that the potential gradient device did not completely cancel this unusually large aircraft charge. On the descent the instrumentation was usually turned off several hundred feet above the fround as a safety precaution because the inverter which provided power for several of the instruments taxed heavily the available aircraft power at low throttle, as on the "approach for landing. Comparisons of ascent,and descent potential gradient measurements occasionally taken to the surface indicate that above 300 to 500 feet the aircraft charge has decayed sufficiently to not effect the potential gradient.

DATA PROCESSING

The data were prepared for analysis in the following manner. The oscillograph charts were edited and the data were reduced to punch-card form with an "Oscar K", an analog digital data reduction'instrument. The cards were then processed by an IBM-7094 computer which applied calibrations to the various parameters. The computer output was plotted on a cathode ray-tube in the form of data versus altitude and then photographed. Prints made from the film were used for the analysis.

The total conductivity of the air was calculated' with the computer by adding each positive conductivity measurement with the preceding negative measurement and vice versa. The conduction current density i in amps m^{-2} was determined at all levels from the formula

$$i = F \lambda$$

where F-is the potential gradient in volts m^{-1} and λ the total conductivity in mho m^{-1}.

The space charge distribution wa s found with Poisson's relationship by differentiating the potential "gradient as follows:

$$\rho = -\varepsilon \frac{\partial F}{\partial Z}$$

where p is the space charge concentration in coulombs m^{-3}, e the permitivity of the atmosphere, and Z the height in meters. The calculation assumes that the atmosphere is in a state of quasistatic equilibrium, a condition which is met throughout most of the sounding during the forenoon but may be deviated . from to a small degree within the afternoon exchange layer.

RESULTS

Figure 2 shows a typical set of soundings taken on July 25. The AM sounding was flown from 0820 to 0910 CST in clear skies, but with several haze levels. The PM sounding, flown from 1415 to 1500 CST, was with <0.1 cumulus.

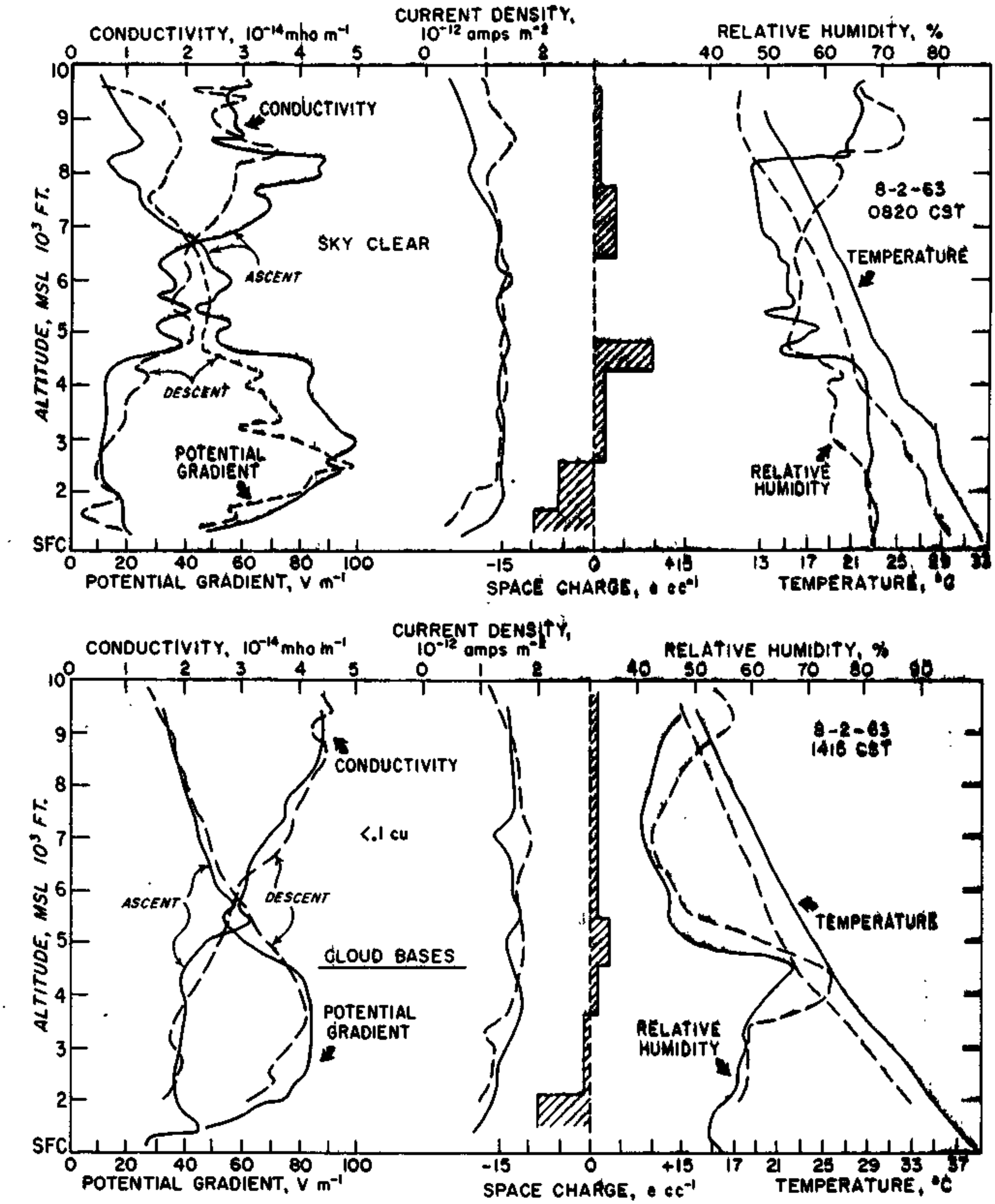

Fig. 2. Soundings of August 2, 1963, West Plains, Missouri.

A characteristic typical of most of the AM soundings is an increase in the potential gradient with increasing altitude up to 2500 feet or 3500 feet, while the conductivity decreases slightlyor remains constant; Above this level the potential gradient gradually decreases"and'the conductivity gradually increases to the top of one or more haze levels where sharper changes occur. On the PM soundings, the altitude and magnitude of the maximum potential gradient is usually greater than in the morning, although this is not completely the situation in Figure 2. The potential gradient increases with increasing altitude up to or within a few hundred feet of the cumulus cloud bases, if clouds exist. It then decreases rather abruptly with increasing altitude up to the vicinity of the cloud tops where the decrease with increasing altitude becomes more gradual. Most of the sounding characteristics described above are also apparent in the average AM and PM potential gradient, conductivity, and current soundings shown in Figure 3.

The West Plains potential gradient soundings are not unlike soundings taken in east central Illinois during the summer of 1960 as described by Moore et al.[5], and similar soundings taken by the author and R. G. Semonin of the Illinois State Water Survey during the summer of 1962 (unpublished). These soundings were often characterized by a potential gradient increasing with altitude within the first 1000 or 2000 feet above the surface, or up to or just below the cloud base level.

The vertical variation of conductivity and potential gradient can be, for the most part, explained with the conventional physical model of the atmosphere. A current flowing from the ionosphere to the earth across the resistance of the atmosphere results in a potential drop or potential gradient throughout this region. The conductivity of the air is the result of

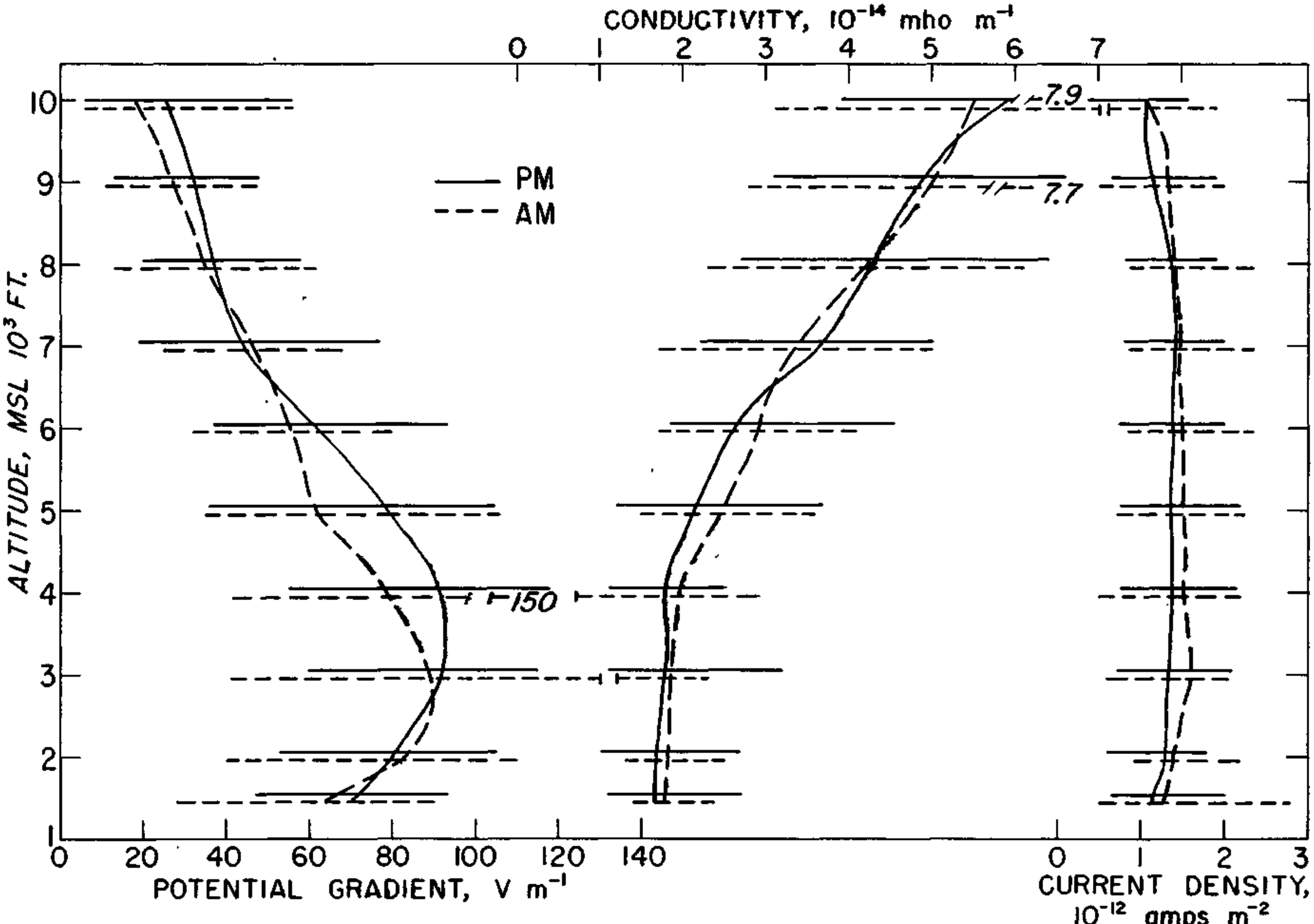

Fig. 3. Average electrical soundings for all flights with limits of variation.

ionization of the air by radioactivity irr the soil and air', and cosmic radiation. The conductivity is nearly constant throughout the exchange layer where thorough mixing tends to promote a homogenous distribution of nuclei. Above the exchange layer or cloudbase altitude the decrease in nuclei concentration is rapid. Fewer nuclei for fast ions to be trapped on plus greater ionization from cosmic radiation at higher elevations results in an increase in conductivity and decrease in potential gradient with increasing altitude.

The current soundings in Figures 2 and 3 show the current to be less near the top and bottom of the soundings, with random variations with altitude in between. The variations in the current density with altitude indicate that the atmosphere is not in a perfect state of quasi-static equilibrium, although the reasonably good agreement that' exists between ascent and descent electrical parameters suggests that it is not too far from a steady state.

The initial increase in the potential gradient with increasing altitude is not always accompanied by a corresponding decrease in conductivity. The conduction current density i calculated from λ and F sometimes increases with increasing altitude in the first 1000 to 2000 feet. The reason for the decrease in i near the surface on many of the flights is not clear. It may be the result of a convection current lifting negative space charge upward 1000 to' 2000 feet or more. The integration of the potential gradient curve as shown in Figure 2 indicates negative space charge within this layer, but the physical means by which the charge might be lifted is uncertain. Kraakevik[6] discusses processes by which a convection current might be formed in the exchange layer. He suggests that the space charge may be attached to condensation nuclei which follow their own laws of diffusive separation. The increase in i with increasing altitude near the surface in the presence of negative space charge is similar to, but opposite the decreases in current density with increasing altitude found by Kraakevik[6] over the oceans in the presence of positive space charge. Over land, Kraakevik reported a higher current density and greater range of variation of i within the exchange layer up to an altitude of 8500 feet than above. On many of the West Plains soundings, i decreased above about 8500 feet, but this elevation is 2000 to 3000 feet above the top of the PM exchange layer so the decrease in i is not directly associated with the top of - the exchange level. Because the West Plains soundings were taken to only 10,000 feet and not above, it is not known whether the current would have stabilized at a lower value above that altitude. Unfortunately, the variations in i were too erratic to establish a definite convection current for each flight.

The potential gradient curves were integrated to a height of 9500 feet to determine the total potential at that altitude. The current varied considerably with altitude so the average current"for a sounding was determined by laying a straight edge through the curving line of the sounding and removing the average. The ascent and descent were determined separately, but the average for the flight was the average of both the ascent and descent.

The time variation of the potential and current density is shown in Figure 4. In most cases there is fairly good agreement between the ascent and descent values of the parameters except on July 18, 19, and 20. On these dates a spare potential gradient transducer was being used while the original was being repaired. Apparently, the spare was not as well balanced and, perhaps, differences in aircraft charge between ascent and descent gave the descents a consistently higher potential gradient. The measurements were retained, however, because they were not in total disagreement with the other

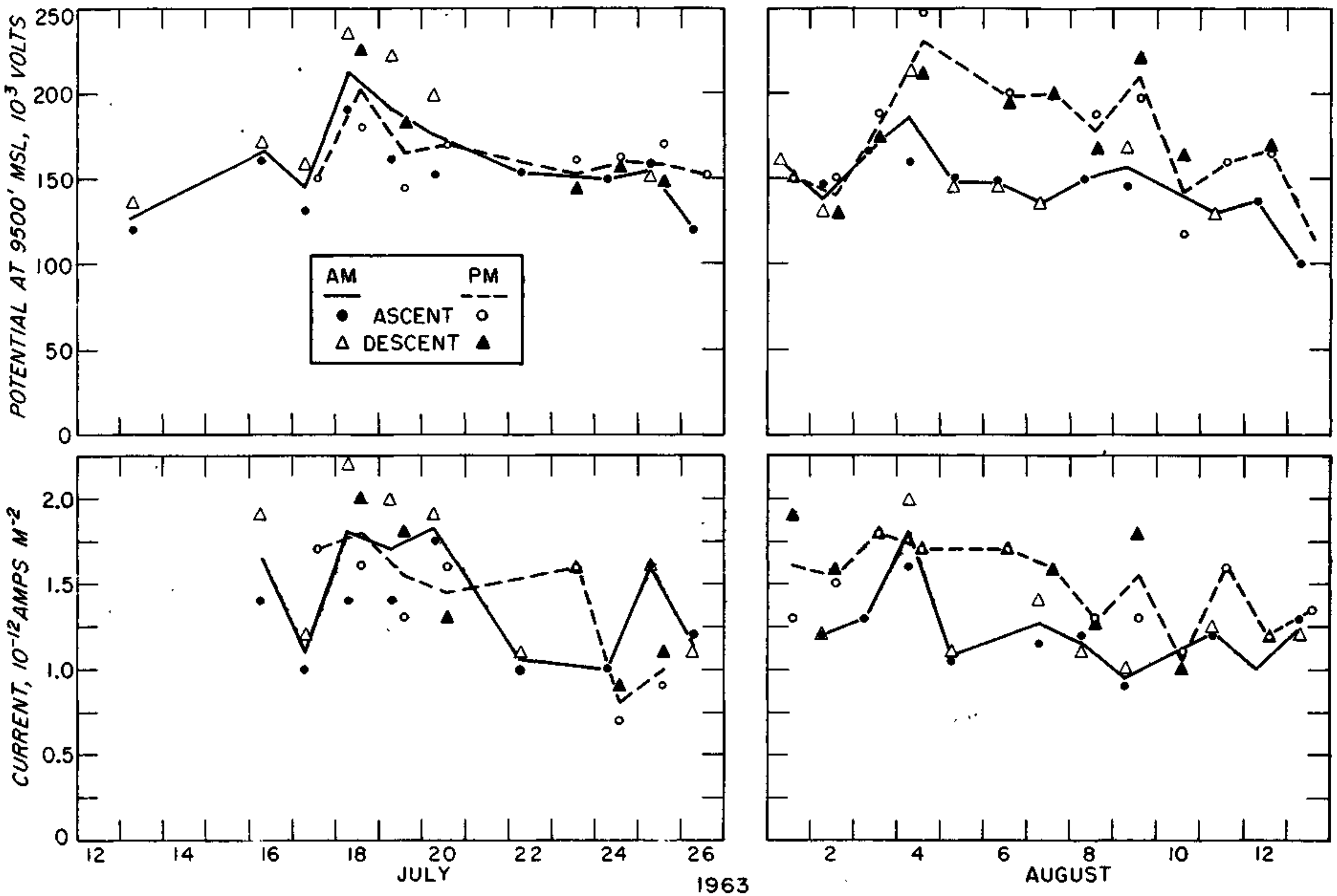

Fig. 4. Daily variation of potential at 9500 ft msl and current density.

measurements.

It is interesting to note that for the July measurements the AM and PM potential values are nearly identical" while during August they differed considerably. Day-to-day variations~in the potential are related to variations in the current but are not directly proportional to them, indicating the varying influence of the columnar resistance between 9500 feet and the surface. Variations in i between AM and PM soundings that might be caused by the normal diurnal variations in the ionospheric potential are very small, amounting to less than 5 percent, according to Chalmers.[7]

Figure 5 is a histogram of the potential frequency distribution for potentials at 9500 feet. The PM potentials tend to average higher than the AM, but as was shown in Figure 4, most of the differences between the AM and PM potentials occurred during the August soundings, that is, the second half of the soundings. An inspection of Figure 4 shows that during August, the PM currents were often higher than the AM currents, thus tending to cause a higher average PM potential. The tendency for higher PM currents is also apparent in Figure 6, a histogram of the current density frequency distribution. The currents vary from 0.8-2.0 x 10^{-12} amps m^{-2} with an average near 1.4 x 10^{-12} amps m^{-2}.

COMPARISON OF RAIN AND NO-RAIN DAYS

A study was made to determine if the atmospheric electrical soundings preceding precipitation were significantly different" from those soundings which were not followed by precipitation. The flights were initially examined in a number of ways with little success to determine if the pre-rain flights differed in any manner from the no-rain flights. Finally, all soundings were compared according to the general shape and magnitude of the potential gradient

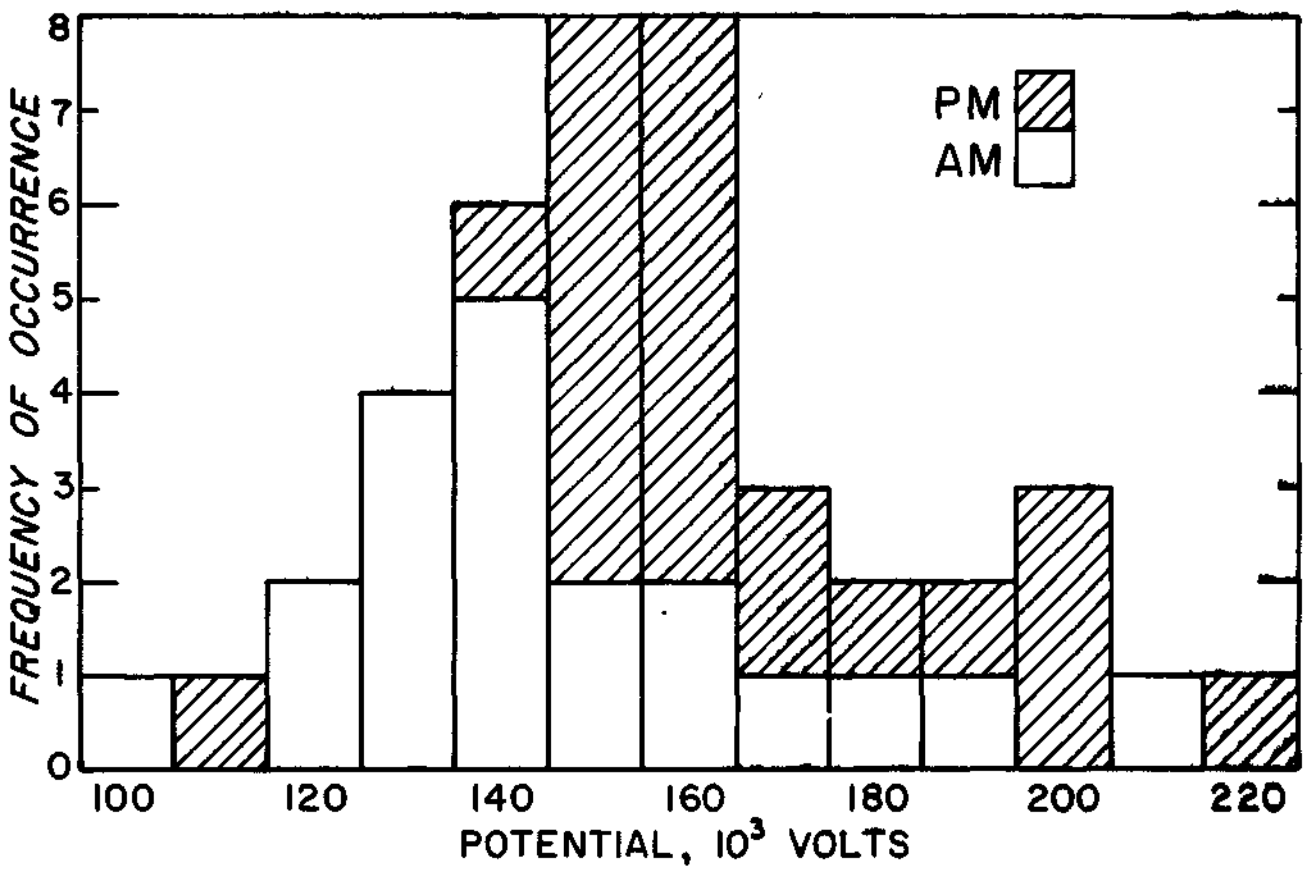

Fig. 5. Potential at 9500 ft msl frequency histogram.

curves, with the following results.

To minimize the influence of previous rainfall on the soundings, data were used in this portion of the analysis only when there was no rainfall on the network during the 1.5 to 2.0 hours preceding the sounding. The average sounding times were approximately 0830-0930 CST and 1415-1515 CST. AM soundings were therefore discarded if rainfall occurred on the network during the hours of 0700-0900 CST, and the PM' sounding was not used if precipitation occurred between 1300 and 1500 CST.

Each sounding was arbitrarily chosen to be representative of the atmospheric electrical condition of the area for the 5 hours following the sounding, i.e., from 0900 to 1400 for the AM sounding and from 1500-2000 for the PM sounding. Only 10 hours of the daily precipitation were considered. A sounding was called a "pre-rain" sounding if there was rainfall anywhere on the network (Fig. 1) during the next 5 hours and a "no-rain" sounding if no precipitation occurred during that period. Radar data were not available on most of the precipitation days considered, but" an examination of the hourly rainfall data strongly indicates that all of the precipitation was convective.

For the AM soundings there were 16 flights meeting the condition of no-rain in the past 1.5 to 2.0 hours. Of these 16, three were followed by rain in the next 5 hours, and 13 were not. The general characteristics of the three flights followed by rain were not unlike the no-rain flights in shape and magnitude below 6000-8000 feet, but above these elevations, there appeared to be two distinct categories of potential gradients. One group of 12 soundings had lower potential gradients of 12 to 28 vm^{-1} at 9000 feet, while the second group of 4 soundings had higher potential gradient values from 35 to 50 vm . The three pre-rain soundings fell into the first

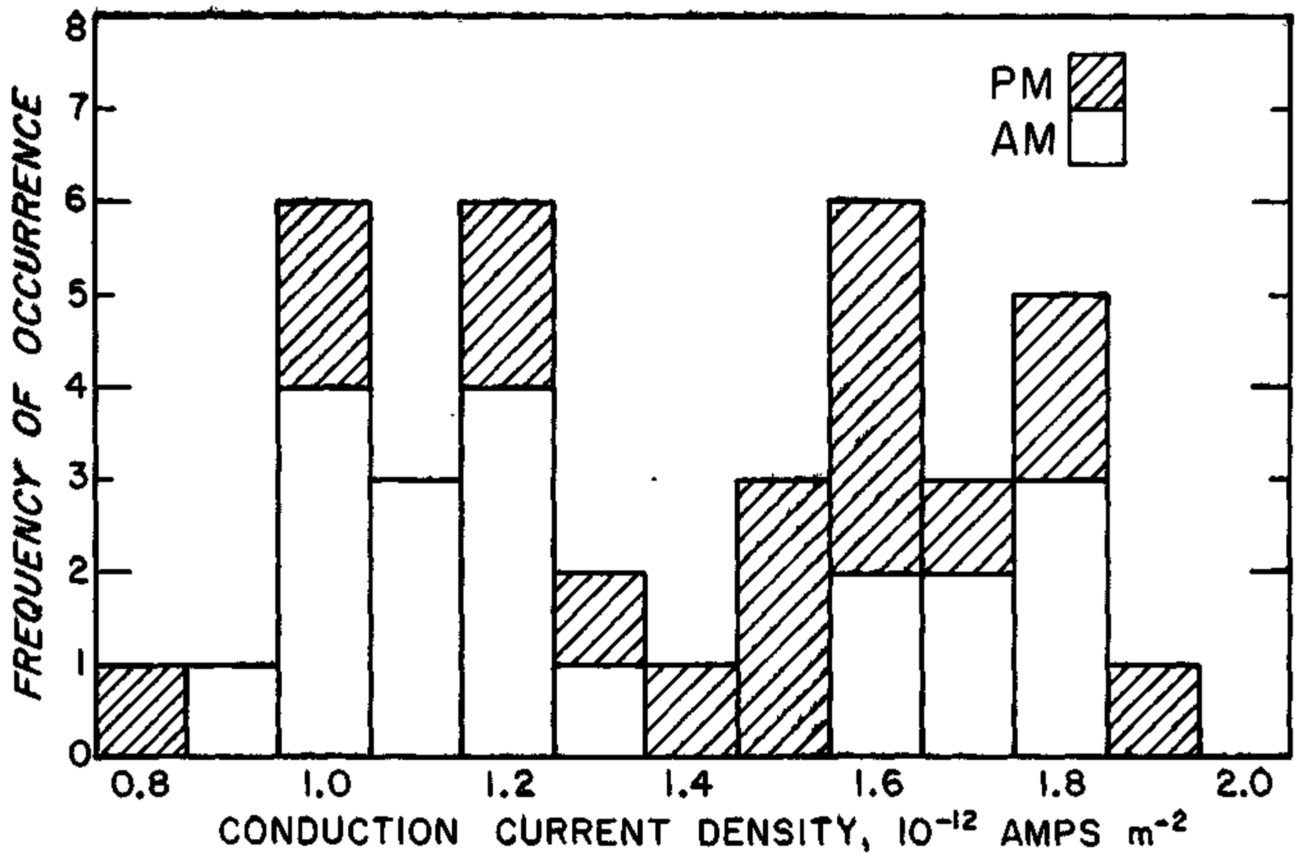

Fig. 6. Current density histogram.

lower group of 12 soundings and were not distinguishable from the no-rain soundings in that group.

In search of an explanation of the above" mentioned stratification of the data, the rainfall records for the preceding day were examined. It was found that 9 out of the 12 AM soundings with lower potential gradients at 9000 feet were preceded by precipitation the day before. In contrast, 3 out of 4 of the group with higher gradients at 9000 feet were preceded by days without precipitation, and the precipitation preceding the fourth sounding occurred at only one station.

The difference between the two types of soundings might be explained by presuming the upper air was so cleansed of particulate matter by the precipitation the day before that the conductivity increased and the potential gradient decreased. This speculation-presents some difficulty, however, because the precipitation data for the day before were obtained from the rain-gage network centered around West Plains, and it is not.known whether precipitation occurred the previous day inthe same parcel of air in which the sounding was taken.

There were also 16 PM flights meeting the conditions of no-rain in the last 1.5 to 2.0 hours, and five of these were followed by precipitation. Again, below 7000 feet, the pre-rain flights resembled the no-rain flights in general shape and magnitude of the potential gradient curve, but above 7000 feet the potential gradients on the pre-rain soundings were between 35 and 50 vm^{-1}, while 55 percent of the no-rain soundings had potential gradients between 15 and 30 vm or approximately half as large. The remaining 45 percent of the no-rain soundings had gradients of the same order of magnitude as the pre-rain sounding. Upon examination of the observer's flight notes for these five high gradient, no-rain flights, it was found that on 4 of the

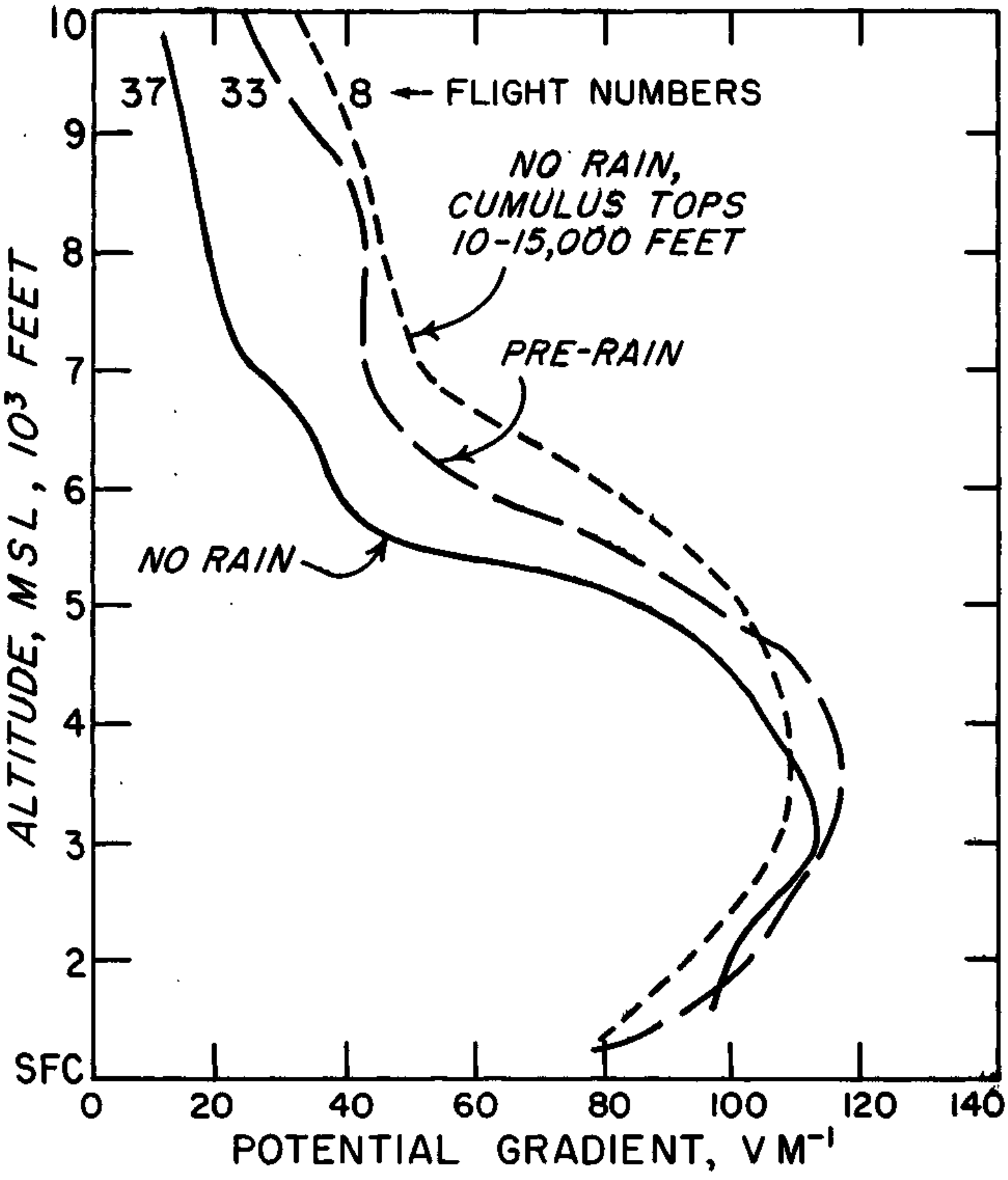

Fig. 7. Potential gradient soundings representative of no-rain, pre-rain, and no-rain with cumulus tops 10-15,000 ft.

5 soundings there was evidence of vertical mixing' above the usual 4000 to 7000 feet of the normal cumulus clouds. Congestus clouds with tops to 10,000 feet or more were within view.' Figure 7 shows three representative soundings and illustrates the similarity between the pre-rain sounding and the no-rain with mixing to 10,000 feet, and how they both differ from the other no-rain sounding.

It appears that the high potential gradients between 7000 and 10,000 feet are the result of convection to those elevations. Extra particulate matter is brought to those altitudes by convection with a subsequent decrease in the number of fast ions, lowering the conductivity, and increasing of the potential gradient. Inspection of the conductivity data substantiates this hypothesis. This condition exists during days with scattered rainfall but is also present on rainless days with convective activity extending to a moderately high level. The high potential gradients are not then a quality indigenous to rainfall days only, but also a quality of days with strong vertical mixing to altitudes of at least 10,000 feet.

The data suggest that in the few hours preceding precipitation there are no major differences in the electrical nature of the atmosphere up to 10,000 feet msl between days which do and do not produce precipitation. If the Vonnegut mechanism is operative in convective precipitation and if the electrification does help promote the precipitation, this experiment did not find evidence suggesting that a specific atmospheric electrical condition must exist for the mechanism to be activated.' That is, the initiation of precipitation is not dependent upon a unique large scale electrical state of the atmosphere, such as a specific space charge concentration or distribution, or a particular polarity of charge. However, this neither proves nor disproves the Vonnegut hypothesis, because no unique space charge distribution was actually stipulated therein.

Although the normal fair-weather space charge is usually considered to be positive, negative space charge was usually encountered in the first few thousand feet on the West Plains soundings;' This implies that if Vonnegut's charging mechanism was in effect, clouds would be charged with negative tops and positive bottoms, which is opposite to the conventional thunderstorm dipole configuration. Vonnegut's charging mechanism can, however, in theory, operate on charge of either polarity.

CONCLUSIONS

1. The potential gradient usually increases from the surface to about 2500 feet in the AM and to about 3500 feet in the PM where it then begins to decrease to at least 10,000 feet. The conductivity is nearly constant with increasing height to around 4000 feet where it begins to increase above the PM exchange layer. The current is somewhat variable with altitude but often increases in the first 1000 or 2000 feet and decreases slightly between 8000 and 10,000 feet.

2. The characteristics of the AM soundings are partially dependent upon the occurrence of precipitation in the same area on the preceeding day, although the nature of the relationship is vague.

3. The PM soundings have higher than normal potential gradients above 7000 feet on days when there is convection above that elevation, but the days where the soundings were followed by precipitation are not distinguishable from rainless days also having vertical mixing to 10,000 feet or higher.

4. The initiation of precipitation appears not to be dependent upon a unique, large scale electrical state of the atmosphere, such as a

a particular space charge concentration of distribution, or a specific polarity of charge.

5. The fair-weather atmospheric space charge over Missouri is usually negative between 1500 (500 feet above the surface) and 2500 to 3500 feet msl, and then positive up to 10,000 feet.

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